LORENTZ SYMMETRY VIOLATION AT PLANCK SCALE, COSMOLOGY AND SUPERLUMINAL PARTICLES

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Although Lorentz symmetry has been tested at low energy with extremely good accuracy, its validity at very high energy is much less well established. If Lorentz symmetry violation (LSV) is energy-dependent (e.g. $\propto E^2$), it can be of order 1 at Planck scale and undetectable at GeV scale or below. Similarly, superluminal particles with positive mass and energy (**superbradyons**) can exist and be the ultimate building blocks of matter. We discuss a few cosmological consequences of such a scenario, as well as possible experimental tests.

1 Lorentz symmetry violation and superluminal particles

"Experiment has provided numerous facts justifying the following generalization: absolute motion of matter, or, to be more precise, the relative motion of weighable matter and ether, cannot be disclosed. All that can be done is to reveal the motion of weighable matter with respect to weighable matter" (H. Poincaré, 1895)

"Such a strange property seems to be a real coup de pouce presented by Nature itself, for avoiding the disclosure of absolute motion... I consider quite probable that optical phenomena depend only on the relative motion of the material bodies present, of the sources of light and optical instruments, and this dependence is not accurate... but rigorous. This principle will be confirmed with increasing precision, as measurements become more and more accurate" (H. Poincaré, 1901)

"The interpretation of geometry advocated here cannot be directly applied to submolecular spaces... it might turn out that such an extrapolation is just as incorrect as an extension of the concept of temperature to particles of a solid of molecular dimensions" (A. Einstein, 1921)

1.1 Status of the Poincaré relativity principle

The Poincaré relativity principle [1,2] has been confirmed by very accurate low-energy tests [3,4], but its validity at much higher energies is not obvious [5,6]. The possibility that special relativity could fail at small distance scales was already considered by A. Einstein [7]: it is remarkable that the relativity principle holds

at the energies attained by particle accelerators. Experiments devoted to the highest-energy cosmic rays may provide crucial tests of Lorentz symmetry [5].

1.2 Lorentz symmetry violation (LSV)

Lorentz symmetry can be broken introducing a local absolute rest frame (the vacuum rest frame, VRF) and a fundamental distance scale a [5]. If LSV follows a $\propto\ E^2$ law (E = energy), it can be ≈ 1 at Planck scale and $\approx\ 10^{-40}$ at the $\approx\ 100\ MeV$ scale, escaping all low-energy tests of Lorentz symmetry. But a $\approx\ 10^{-6}$ LSV at Planck scale can produce [5] obervable effects at the highest cosmic-ray energies ($\approx\ 10^{20}\ eV$). If k is the wave vector, nonlocal models lead in the VRF [5] to a deformed relativistic kinematics which for $k\ a\ \ll\ 1$ gives:

$$E\ \simeq\ c\ (p^2\ +\ m^2\ c^2)^{1/2}\ -\ (c\ \alpha/2)\ (p\ k\ a)^2\ (p^2\ +\ m^2\ c^2)^{-1/2} \qquad (1)$$

where p stands for momentum, m for mass and α is a positive constant.

1.3 Deformed relativistic kinematics (DRK)

Contrary to the $TH\epsilon\mu$ model [8], DRK preserves relativity in the limit $k\ \rightarrow 0$. A fundamental question is that of the universality of α : is α the same for all bodies, or does it depend on the object under consideration? If c is universal and $\alpha\ \propto\ m^{-2}$, equation (1) amounts to a relation between E/m and p/m , as in relativistic kinematics. From a naive soliton model [9], we inferred that: a) c is expected to be universal up to very small corrections ($\sim\ 10^{-40}$) escaping existing bounds; b) an approximate rule can be to take α universal for leptons, gauge bosons and light hadrons (pions, nucleons...) and assume a $\alpha \propto m^{-2}$ law for nuclei and heavier objects, the nucleon mass setting the scale.

1.4 Cosmic superluminal particles (CSL)

If Lorentz symmetry is broken at Planck scale, nothing prevents the existence of particles with positive mass and energy and critical speed in vacuum c_i (the subscript i stands for the i-th superluminal sector) much larger than the speed of light c [6]. Such particles (**superbradyons**) could be the ultimate building blocks of matter from which, for instance, strings would be made. They can satisfy the same kinematics as "ordinary" particles, but replacing the speed of light c by the new critical speed c_i , and interact weakly with "ordinary" matter. Nonlocal models at Planck scale may be the limit of an underlying superluminal dynamics in the limit $c\ c_i^{-1}\ \rightarrow\ 0$. CSL can possibly propagate in vacuum just like photons in a perfectly transparent crystal.

2 Some cosmological implications

It was suggested [10], using a different DRK from (1), that DRK could explain the dark matter problem: the non additivity of rest energy for non interacting systems at rest would account for the illusion of a missing mass. But it was later argued [11] that the effect would actually be opposite to observation. However, both authors use a model where the additive quantity, instead of energy, is:

$$F\ (m\ ,\ E)\ \ =\ \ 2\ \kappa\ (m)\ \ sinh\ [2^{-1}\ \kappa^{-1}\ (m)\ E] \tag{2}$$

and the constant κ (similar to the parameter α of our model) has a universal value. There is no fundamental reason for this universality and similar arguments to those developed for our DRK model would suggest [9] $\kappa \ \propto \ m$, restoring the additivity of rest energy for large non interacting systems at rest.

A generalization of Friedmann equations in the presence of superluminal sectors of matter can be built [12] and does not present inconsistency with data. Superluminal particles may actually be most of the cosmic (dark) matter.

References

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